*Correlación entre el Índice
RMR de Bieniawski y el Índice
Q de Barton en Suelos de
Baja Calidad*

Correlation between Bieniawski's RMR and Barton's Q Index in Low-Quality Soils

Autores

- CASTRO-FRESNO, D.** Professor of Construction Engineering.
University of Cantabria
email: castrod@unican.es
- DIEGO-CARRERA, R.** Master Civil Engineer
PhD. Student. University of Cantabria
email: diegor@unican.es
- BALLESTER-MUÑOZ, F.** Professor of Construction Engineering.
University of Cantabria
email: ballestf@unican.es
- ÁLVAREZ-GARCÍA, J.** Civil Engineering
MSc in European Construction Engineering. PAYMACOTAS
email: juanjoalvarez@msn.com

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Abstract

The appropriate sizing of the strutting sections of a tunnel depends on the adequacy of the parameters initially used to perform the calculation. A very common practice in underground engineering is to make an estimation of the strutting through the use of geomechanical classifications. Nowadays, the most widely used classifications are Bieniawski's RMR Quality Index and The Barton et al. Q Quality Index.

The research work carried out aims to provide a correlation between the two quality indexes, with the intention of supplying a tool to aid in both the design phase and the daily control of work execution. The formulas were obtained from the on-site observation of rocky masses of low and very low quality, so the application range extends to that kind of soils.

Key words: Geomechanics, tunnelling, underground construction, strutting, quality index, RMR-index, Q-index.

Resumen

El apropiado dimensionamiento de las secciones de sostenimiento de un túnel depende del ajuste de los parámetros usados inicialmente en la ejecución de los cálculos. Una práctica muy común en ingeniería de obras subterráneas es hacer una estimación del sostenimiento a través del uso de las llamadas clasificaciones geomecánicas. A día de hoy, las clasificaciones universalmente más utilizadas son el Índice RMR de Bieniawski y el Índice Q de Barton et al.

El trabajo de investigación desarrollado se centra en proporcionar una correlación entre los dos índices de calidad, con la intención de proveer una herramienta que ayude en las fases de diseño y en el control diario de la ejecución de los trabajos constructivos. Las fórmulas se han obtenido de la observación in-situ de macizos rocosos de mala y muy mala calidad, por lo que el rango de aplicación se circunscribe a este tipo de suelos.

Palabras clave: Geomecánica, excavación de túneles, construcciones subterráneas, sostenimiento, índices de calidad, Índice RMR, Índice Q

1. Precedents

Throughout the last decades, many authors have published empirical correlations, relating Bieniawski's RMR Quality Index (Bieniawski. 1973) and Barton's Q Quality Index (Barton N. et all. 1970). The most widely used examples are:

Bieniawski. (Bieniawski. 1984)

$$RMR = 9 \cdot \ln Q + 44 \quad (1)$$

Rutledge and Preston. (Rutledge and Preston. 1978)

$$RMR = 5,9 \cdot \ln Q + 43 \quad (2)$$

Moreno. (Moreno Tallon. 1980)

$$RMR = 5,4 \cdot \ln Q + 55,2 \quad (3)$$

Cameron-Clarke and Budavari (Cameron-Clarke and Budavari. 1981)

$$RMR = 5 \cdot \ln Q + 60,8 \quad (4)$$

(Abad J et all. 1987)

$$RMR = 10,5 \cdot \ln Q + 41,8 \quad (5)$$

The graphic shows the existing differences between these authors' proposals:

As can be seen, for the central values of the Quality Indexes, all authors tend to agree on the figures obtained, but at the extremities of the classifications the biggest differences can be seen between the results obtained with the different formulations.

Between the two extremities ("excellent" and "very low" quality), the "low" and "very low" quality are the ones that have to be studied, due to the fact that in high-quality soils the calculation of the strutting elements required to support an underground work involve little effort.

Each of the previous expressions have arisen from a series of specific data, taken on a determined worksite, with the special conditions of the precedence place. This means that the validity of these expressions is strongly dependent on precise knowledge of the original data from which they were deduced. Consequently, none of these expressions is universal nowadays.

2. Objectives

The objective of the research carried out is to obtain an empirical correlation between the most widespread Quality Indexes, Bieniawski's RMR Quality Index (Bieniawski. 1973) and Barton's Q Quality Index (Barton N. et all. 1970). The study focuses on obtaining an interrelation between those parameters, based on the survey of low and very low-quality soils.

Graphic 1
Existing differences between authors' proposals

One of the main uses of geomechanical classifications is the estimation of the required strutting by a determined underground works. The election of the strutting elements in low-quality terrains is, without doubt, one of the critical decisions in an underground project.

Counting on a formulation that allows the instantaneous calculation of the Q Quality Index from the RMR Quality Index taken onsite (or vice versa) would provide a very helpful tool in the decision-making process, because two parameters are available providing two suggestions for strutting from the same original information. In this way, the technician in charge of analyzing the type section of the strutting for each step of the excavation has more information to rely on.

The empirical formulation resulting from this research is aimed at providing an additional correlation that professionals can use when working with low and very low-quality soils.

In addition to this, the characteristics of the soil where the geotechnical information was gathered will be registered, so the engineer will be aware of the source of the data leading to the proposed formulation. This is basic for a good practice.

3. Description of the “El Fresno” tunnel

The “El Fresno” Tunnel forms part of the Grado (W) – Doriga section of the A-63 Highway in Asturias, constructed with funding from the Spanish Government. It consists of a constant radius, twin tube road tunnel excavated by conventional means. The length of the roadways is 949m for the left side one and 928m for the right side one, both carriageways having a constant slope of 0.6%.

The tunnel geometry is highly dependent on the soils through which the tunnel passes, in general bad quality, with values of the RMR Quality Index usually under 30. Furthermore, in the Tertiary part, there are some cohesionless zones presenting extremely bad geotechnical conditions.

4. Geological and geotechnical characteristics

4.1 Geology of the tunnel

The materials affected by the tunnel excavation are Tertiary and the Paleozoic.

Paleozoic – Devonian – Rañeces’ Complex: This formation is mostly grey calcareous litologies with slate intercalations, of a thickness of 600-700 m.

Tertiary: Over the Paleozoic materials there are a series of detritic deposits, in the ground of 300 -400 m in depth, from the Tertiary period. The composition of these materials is highly irregular, with predominance of consolidated clays (argillite) and sand lenticles. Between those levels there are also randomly distributed gravels and conglomerates of low cementation, carbonate layers (marl clay), intercalated without a defined structure.

To be more accurate, the trace of the tunnel in this zone goes through marls, sandy marls, sandy clays with little carbonization and conglomerates with different levels of cementation.

4.2 Structure

The stratification of the soils in the tunnel zone has, approximately, a parallel direction to the tunnel axis, with a dip greater than 45° to the west.

The joints have continuity, over 1m, with a moderate spacing of 20 to 60 cm, partially open on surface (less than 1cm). Generally, the structure shows moderate meteorization and weak meteorization in deep range.

4.3 Hydrogeology

The main groups of soils have different behaviour from the hydro-geological point of view.

Paleozoic – Devonian – Rañeces’ Complex: In healthy state, these soils are impermeable, but several processes of karstification ensure a good level of permeability. The water flow is guaranteed by the steep slopes and the connections among karstified conducts.

Table 1
Technical data of "El Fresno" tunnel

SPECIFICATIONS			
Name	EL FRESNO		
Tunnels			
Number of tubes	2 (left and right roadways)*		
Separation between tunnels	Between axis: from 35 to 42m Between excavation profiles: 20 to 27m		
Functional Type Section			
Width of roadway	10.5m Hard strip (1m) + Line (3.5m) + Line (3.5m) + Hard strip (2.5m)		
Sidewalks	Width and height variable with the slope Approximately: 1.5m in the superior and 1.4 in the inferior sidewalk.		
Geometry of the internal section	Circular, one centre only. Height from midpoint of roadway: 1.05m Tunnel axis = Roadway axis.		
Geology	Left Roadway		Right
Roadway			
Materials crossed	Tertiary: clay, sandy clay gravel.	20+504 – 21+165	10+499 – 11+060
	Devonian (Rañeces Complex): limestone, slate.	21+165 - 21+408	11+060- 11+377
Maximum soil covering	146 over grade line		
Tunnel Length	Left Roadway		Right Roadway
K.P. False tunnel (east)	20+478		10+473
K.P. Tunnel entrance (east)	20+504		10+499
K.P. Tunnel entrance (west)	21+408		11+377
K.P. False tunnel (west)	21+427,5		11+396,5
Length	Total: 949.5m Length in false tunnel: 45.5m Length in tunnel: 904m		Total: 923.5m Length in false tunnel: 45.5m Length in tunnel: 878m

Tertiary: Composed mostly of clay-based materials, should be impermeable. But the presence of gravel-based materials intercalated at various levels could lead to hanging deposits of water. Due to the random situation of these intercalated levels, it is impossible to determine the location of deposits.

4.4 Excavation and strutting

A detailed description is included of the excavation and strutting methodologies required in the construction of the tunnel, as well as the application field.

4.5 Excavability

There are tertiary soils in more than 75% of the total, and they are excavated with traditional media, (excavator with hammer or shearer machine).

The Devonian massif was removed through perforation and blast in almost all its extension and only in the hardest parts were mixed methodologies used (pre-blast and excavator with hammer).

5. Geomechanical survey of the excavation front

The Geologist of the Technical Assistance team in charge of the monitoring of El Fresno Tunnel visits the excavation front daily, executing a survey based on Bieniawski's RMR (Rock Mass Rating) Quality Index, obtaining a characterization for each of the litologies present at the excavation front. The final result of the inspection is the weighted mean value of all the litologies analyzed.

Next, the standardized form where the Geologist summarizes the information gathered in-situ is shown.

6. Statistical processing of the parameters

6.1 Introduction

From the in-situ data acquisition and its analysis, a correlation between the RMR Index and the Q Index is

established. Using the data compiled by the Technical Assistance Team, it is possible to determine the Q Index value in the same conditions as the RMR ones (measured at the excavation front).

Thus, for each stage in the excavation, two different Quality Index values are available. This can be considered as the starting point for establishing correlations between Quality Indexes.

As commented before, the main idea of this work is to establish an applicable correlation for bad and very bad quality soils. Following this philosophy, the Devonian materials present in El Fresno Tunnel are the most suitable for this purpose and are the ones used in this research.

It should be pointed out that the resultant correlations are obtained exclusively from values of RMR under 50 (approximate equivalent $Q \cong 2$). This means a generalized low-quality Devonian material.

6.2 Criteria of validation of results

To analyze the results obtained, the R coefficient (Pearson's coefficient for correlation) was used. This coefficient provides information about the degree of relationship between two variables (RMR and Q in this case). If the relation is perfectly linear, R will be equivalent to -1 or +1, depending on the sign of the relation.

In general, values of $R > 0.80$ are considered high, but this depends on the number of pairs of data involved in the calculation and the level of certainty desired to extract conclusions. Without entering deeply into a study of significance of the R coefficient as an indication, it can be said that with 11 pairs of data and a 5% error, an $R > 0.553$ can demonstrate the dependence of the two variables. With 50 pairs of data, $R > 0.273$ can justify the same conclusion.

In a more strict manner, with only a 1% chance of a mistake, with 11 pairs, $R > 0.684$, and with 50 pairs of data, $R > 0.354$ is enough to confirm that the correlation exists.

Another parameter used to analyze the results obtained is the Coefficient of Determination (R^2). If a certain correlation has a Coefficient of Determination of X%, it means that the X% of the RMR Index is in

Figure 1
Geologist information fill form

PARTE DIARIO DE TÚNELES DEVONICO		GRD- 32																			
Autovía A-63 Oviedo - La Espina, Tramo: Grado - (O) Doriga																							
Clave: 12-O-4840																							
Nº PASE: 17		TÚNEL: LD T3		PK DEL FRENTE: 21+379																			
MÉT. DE EXCAVACIÓN: Voladura		SOSTENIMIENTO: S-3		FECHA: 4-Oct-07																			
LITOLOGÍA DEL FRENTE:		Grupo Rañeces																					
DATOS ESTRUCTURALES: <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>CAPA</th> <th>DESCRIPCIÓN</th> <th>Porcentaje</th> </tr> </thead> <tbody> <tr> <td>A</td> <td>Caliza negra mediana/ventre alterada (G, R). Muy fracturada.</td> <td>60%</td> </tr> <tr> <td>B</td> <td>Arenisca amarilla medianamente alterada (G, R) con una pequeña falla intermedia</td> <td>10%</td> </tr> <tr> <td>C</td> <td>Pizarras grises muy alteradas (G, R) y fracturadas.</td> <td>30%</td> </tr> <tr> <td>D</td> <td></td> <td></td> </tr> <tr> <td>E</td> <td></td> <td></td> </tr> </tbody> </table>						CAPA	DESCRIPCIÓN	Porcentaje	A	Caliza negra mediana/ventre alterada (G, R). Muy fracturada.	60%	B	Arenisca amarilla medianamente alterada (G, R) con una pequeña falla intermedia	10%	C	Pizarras grises muy alteradas (G, R) y fracturadas.	30%	D			E		
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E																							
CROQUIS: <div style="display: flex; justify-content: space-around; align-items: flex-end;"> <div style="text-align: center;"> <p>FRENTE DE AVANCE</p> </div> <div style="text-align: center;"> <p>FOTOGRAFÍA DEL FRENTE</p> </div> </div>																							
SOSTENIMIENTO: S-2		MONTERA: 21 m																					
TRATAMIENTOS ESPECIALES:																							
CLASIFICACIÓN RMR AJUSTADO (BIENIAWSKI, 1989)																							
R.C.S. Mpa		R6	R5	R4	R3	R2 / R1 / R0																	
		>250MPa	100-250MPa	50-100MPa	25-50MPa	5-25 / 1-5 / <1																	
Valoración		15	12	7	4	2 - 1 - 0	4	2	1														
RQD %		90-100	75-90	50-75	25-50	<25																	
Valoración		20	17	13	6	3	6	3	3														
SEPARACIÓN ENTRE JUNTAS		>2m	0,6-2m	0,2-0,6m	0,06-0,2m	<60mm																	
Valoración		20	15	10	8	5	10	15	8														
CONDICIÓN DE LAS JUNTAS	LONGITUD	<1m	1-3m	3-10m	10-20m	>20m																	
	Valoración	6	4	2	1	0	4	6	4														
	ABERTURA	Nada	<0,1mm	0,1-1mm	1-5mm	>5mm																	
	Valoración	6	5	3	1	0	3	5	3														
	RUGOSIDAD	Muy rugos	Rugosa	Ligera rugosa	Ondulada	Suave																	
	Valoración	6	5	3	1	0	3	3	1														
	RELLENO	Ninguno	Relleno duro <5mm	Relleno duro >5mm	Relleno blando <5mm	Relleno blando >5mm																	
	Valoración	6	4	2	2	0	4	6	2														
ALTERACIÓN	Inalterada	Ligera alterad	Mod alterada	Muy alterada	Descompue																		
Valoración	6	5	3	1	0	3	1	0															
FLUJO DE AGUA EN JUNTAS		SECA	LIGERA HUM	HUMEDAS	GOTANDO	FLUYENDO																	
		0l/min	<10l/min	10-25l/min	25-125l/min	>125l/min																	
Valoración		15	10	7	4	0	15	10	10														
RMR BÁSICO							52	51	32	0	0												
ORIENTACIÓN JUNTAS		Muy favorable 45-90° contrav	Favorable 20-45° contraav	Medio 0-50° hacia avance	Desfavorable 20-45° al avan	Muy desfav 45-90° paralelo																	
Valoración		0	-2	-5	-10	-12	-12	-12	-12														
RMR AJUSTADO																							
CLASIFICACIÓN SEGÚN RMR AJUSTADO		Muy buena 100-81	Buena 80-61	Media 60-41	Mala 40-21	Muy mala 20-0	40	39	20	0	0												
OBSERVACIONES E INCIDENCIAS: RMR MEDIO DEL FRENTE: 34 Zona muy alterada por falla cambio a sección S-3																							
REALIZADO POR:		Vº Bº		Distribución: (/ /)																			
David Vigara		Pablo Nistal		Dirección de Obra																			
Fecha y Firma 04/10/2007		Fecha y Firma 04/10/2007		Contratista																			
				Original: Archivo																			

direct relation to the Q Index. So, it represents the proportion of the shared or explained variability.

Using the Coefficient of Determination, it is also possible to determine the proportion of variability not explained, where $Y=100-X$. This can be assumed as Y% of the correlation between the RMR and Q Quality Indexes.

7. Results

7.1 Preliminary considerations

After processing the starting data, the possibility of interrelating Bieniawski's RMR Quality Index and Barton's Q Quality Index is studied using different types of mathematical expressions.

Papers published by many authors correlate the two Indexes with expressions based on logarithms:

$$RMR = a \cdot \ln Q + b \quad (6)$$

Where "a" and "b" are two parameters.

In this research, the following types of equations were used:

Potential law

$$RMR = a \cdot Q^b \quad (7)$$

Linear law

$$RMR = a \cdot Q + b \quad (8)$$

Exponential law

$$RMR = a \cdot e^{b \cdot Q} \quad (9)$$

Polynomial law (2, 3 and 4 degrees)

$$RMR = a \cdot Q^4 + b \cdot Q^3 + c \cdot Q^2 + d \cdot Q + e \quad (10)$$

Logarithmic law

$$RMR = a \cdot \ln Q + b \quad (11)$$

Next, the results obtained are shown, both in graphical and analytical ways.

7.2 Potential correlation

Graphic 2

Potential correlation between Q-RMR Index

The resultant equation for the logarithmic regression is:

$$RMR = 35.632 \cdot Q^{0.2571} \quad (12)$$

$$R^2 = 0.481 \rightarrow R = 0.694$$

This approximation shows the biggest value for R for 0.694, extremely close to the Logarithmic adjustment. Its adjustment shows a level of certainty with a point cloud similar to the logarithmic correlation, but this may not be appropriate for performing a correct extrapolation to the higher part of the graph, and probably for this reason other authors (Bieniawski. 1984; Rutledge and Preston. 1978; Moreno Tallon. 1980; Cameron-Clarke and Budavari. 1981; Abad J et al. 1987) do not use this type of trend line in their articles. Anyway, this correlation is perfectly suitable for the "El Fresno" Tunnel, due to the fact that the material never passes the limit of $Q=2$.

7.3 Linear correlation

Graphic 3

Linear correlation between Q-RMR Index

The resultant equation for the linear regression is:

$$RMR = 13.393 \cdot Q + 22.024 \quad (13)$$

$$R^2 = 0.436 \rightarrow R = 0.660$$

This approximation gives a quite acceptable value for R of 0.4369, not far from the logarithmic adjustment. Due to its mathematical properties of constant slope, this trend line is not appropriate even for the range of values that this study encompasses, but it is not suitable at all for extrapolations. With a simple look at the graph, it is visible that a high level of uncertainty of the equivalence obtained will always be present. In addition to this, the values of Q obtained will be greater than the ones obtained from other correlations with a more "natural" slope.

7.4 Exponential correlation

The resultant equation for the linear regression is:

$$RMR = 21.604 \cdot e^{(0.4753Q)} \quad (14)$$

$$R^2 = 0.369 \rightarrow R = 0.609$$

This approximation shows a quite acceptable value for R of 0.609, not far from the logarithmic and potential adjustments (the best one). Due to its mathematical properties of convexial growth, the equivalences obtained will provide bigger values of Q than other correlations with a more "realistic" growth for the same value of RMR.

7.5 Polynomial correlation (2, 3 and 4 degree)

The resultant equation for the polynomial regression (degree 2) is:

$$RMR = -5.6626 \cdot Q^2 + 22.727 \cdot Q + 19.689 \quad (15)$$

$$R^2 = 0.461 \rightarrow R = 0.679$$

The resultant equation for the polynomial regression (degree 3) is:

$$RMR = 18.096 \cdot Q^3 - 52.766Q^2 + 53.167 \cdot Q + 15.373 \quad (16)$$

$$R^2 = 0.473 \rightarrow R = 0.689$$

Graphic 7

Polynomial correlation degree 4 between Q-RMR Index

The resultant equation for the polynomial regression (degree 4) is:

$$\begin{aligned} \text{RMR} &= -20.965 \cdot Q^4 + 92.506 \cdot Q^3 - 135.04 \cdot Q^2 + 83.903 \cdot Q + 12.551 \\ R^2 &= 0.485 \rightarrow R = 0.696 \end{aligned} \quad (17)$$

In the case of the polynomial correlations, it is visible that with the increase of the degree, the personalization the slopes of the trend line acquire very high levels. This can have a double reading.

On the one hand, in very specialized cases (such as the "El Fresno" Tunnel) this type trend line can provide a very tight equation to obtain the appropriate equivalences between RMR and Q Quality Indexes. However, only when counting in the lowest part of the graph, and counting with plenty and solid values to perform the correlation.

On the other hand, the use of this graph has various disadvantages. For example, it is not easy to use, it always being necessary to calculate a complex equation to obtain the equivalence (eliminating the useful "mental calculation" to have a fast approximation).

Another disadvantage is the absence of the use of these curves in the Construction Industry, and of course, the total impossibility of extrapolating results to materials with better resistance.

To sum up, these curves should obviously not be used.

7.6 Logarithmic correlation

Graphic 8

Logarithmic correlation between Q-RMR Index

The resultant equation for the logarithmic regression is:

$$\begin{aligned} \text{RMR} &= 6.6535 \cdot \ln(Q) + 35.533 \\ R^2 &= 0.493 \rightarrow R = 0.702 \end{aligned} \quad (18)$$

This approximation shows one of the biggest values for R of 0.702. Its adjustment is coherent with a possible extrapolation to the higher part of the graph. This adjustment is the one commonly used by all authors when establishing correlations between RMR and Q Quality Indexes. It is easily visible that the trend line fits the pairs of values well, following the most populated parts of the point cloud in the entire range.

8. Comparison with other authors

As stated, many other authors have published their own correlation for the RMR and Q Indexes, with varied results. The following graph will visually show that the results obtained are very similar to other studies.

Graphic 9
Comparison between authors

The logarithmic correlation obtained:

$$RMR = 6.63 \cdot \ln Q + 35.53 \quad R=0.70 \quad (19)$$

After a preliminary comparison of the different solutions, the first recommendation is to use these correlations with extreme prudence, being extremely cautious about the origin and compatibility of the initial data.

In the equation obtained, the initial data were obtained from an extremely low-quality Devonian material, and bearing in mind the difference between the amount of data used by the other authors, the results obtained are quite acceptable, showing a close correspondence to the results obtained by Abad et al (Abad J et al. 1987) and Bieniawski (Bieniawski. 1984).

Another important aspect to be analyzed is the proximity of the R values in these equations. These classifications have R values in the range of 0.55 to 0.81, when the R value for the correlation obtained is R=0.70.

This shows strong foundations on the generated correlation, with values of R similar to or greater than recognized authorities.

Comparing these results to Moreno (Moreno Tallon. 1980), Rutledge and Preston's (Rutledge and Preston. 1978), and Cameron-Clarke & Budavari's (Cameron-Clarke and Budavari. 1981) it is possible to appreciate that the slope in the graph is similar.

Next, a table with the correlation coefficients and determination coefficients obtained by various authors is shown, in comparison with the ones obtained in this research.

Bearing in mind the difficulty to calculate the RMR and Q Quality Indexes when low-quality materials are involved, the values of the R parameters obtained in the research are much higher than might initially be expected in most of the approximations.

Table 2
Comparison between correlation and determination coefficient obtained by various authors

Approach	Correlation coefficient	Determination coefficient
Bieniawski, 1979	0,77	0,59
Rutledge and Preston, 1980	0,81	0,66
Moreno, 1981	0,55	0,30
Abad et al., 1983	0,66	0,44
Castro, Diego, Álvarez&Ballester, 2008	0,70	0,49

9. Conclusions and recommendations

From the study performed to obtain a specific correlation for the west side of the "El Fresno" Tunnel (Devonian material of very low quality), a series of conclusions can be derived.

Nowadays, geomechanical classifications are a basic tool in order to estimate the required strutting in an underground project. A helpful mathematical formulation that establishes a relationship between the most widely used methodologies provides a significant tool for the professionals involved.

The references given by instruments such as convergence stations or pressure cells are complemented by the strutting recommendations provided by the geomechanical classifications.

In future decision-making situations, another option will be available when choosing the appropriate strutting. The new choice derives from the incorporation of the Q Quality Index in the methodologies to complement the information given by the RMR Index, the instrumentation, and in-situ mechanical prospecting coupled with experience.

In this way, the required strutting can be estimated using the RMR Quality Index, then the correspondent

Q Quality Index can be obtained and finally the required strutting can be reconsidered using Barton.

Taking into account the proposals of the two geomechanical classifications, a more refined decision can be made without the expense of more resources or time, avoiding increments in the responsibility level.

The closeness of the correlation is in many cases better than using other publicly recognized expressions, with a value of $R=0.70$ compared to the average of the correlations used for comparison, which has a value of $R=0.68$.

The added value provided by the correlation lies in the origin of the starting data. As mentioned before, the "El Fresno" Tunnel is being dug through low-quality soils, and as a consequence, the correlation was calculated with pairs of data in the lower part of the RMR and Q Quality Index scales ($RMR < 50$ and $Q < 2$).

In this case, far from being a problem, this is an advantage. That part of the scale is the most difficult to incorporate into a mathematical expression as it is not specially considered in the correlations presented by other authors.

The correlation obtained sheds light on this situation, providing special relevance to the results obtained and opening a window for future development.

10. Future work

This research gives rise to a future line of investigation referring to soils of low and very low quality. The amount of data taken in-situ is an essential factor in the goodness of the final result. In future works, the diverse typologies of low-quality soils will have to be thoroughly studied, searching for more representative correlations.

The interest that the study of terrains of low quality provokes is evident. It is the best possible scenario to carry out an underground excavation. In this case, the correct election of the required strutting combination is a vital task.

As a consequence of this, a future line of action will be to adjust the actual geomechanical classifications in the zones of bad conditions (where the assessments are lower). Once this task is accomplished, the next step will be to redefine with better precision the requirements of strutting according to the principal geomechanical classifications in use.

11. Acknowledgements

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